NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE 2390

FATIGUE STRENGTHS OF AIRCRAFT MATERIALS

AXIAL-LOAD FATIGUE TESTS ON NOTCHED SHEET SPECIMENS OF 24S-T3 AND 75S-T6 ALUMINUM ALLOYS AND OF SAE 4130 STEEL WITH STRESS-CONCENTRATION FACTOR OF 5.0

By H. J. Grover, S. M. Bishop, and L. R. Jackson

Battelle Memorial Institute

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SUMMARY

This report presents results of axial-load fatigue tests on notched specimens of three sheet materials: 24S-T3 and 75S-T6 aluminum alloys and normalized SAE 4130 steel. Each specimen was notched by edge notches designed to have a theoretical stress-concentration factor of 5.0. Tests were run at four levels of nominal mean stress: 0, 10,000, 20,000, and 30,000 psi.

Results of these tests extend information previously reported from tests on unnotched specimens and on specimens less severely notched.

INTRODUCTION

This is the third of a series of reports summarizing work on an investigation of the fatigue strengths of metals used in aircraft construction. This investigation was conducted at Battelle Memorial Institute, under the sponsorship and with the financial assistance of the National Advisory Committee for Aeronautics, with the objective of obtaining basic data on the fatigue properties of three widely used sheet materials: 24S-T3 and 75S-T6 aluminum alloys and SAE 4130 steel.

The first report (reference 1) presented data on the fatigue properties of unnotched specimens of these three materials. The second report (reference 2) contained results of fatigue tests on sheet specimens notched as follows:

(1) With three types of notches (central hole, edge, and fillet) for each of which the theoretical stress-concentration factor was $K_t = 2.0$

(2) With two types of notches (edge and fillet) of greater severity, so that $K_t = 4.0$

The present report contains results of fatigue tests on more severely notched sheet specimens, with an edge notch having $K_t = 5.0$.

The authors wish to thank Mr. Paul Kuhn, of the Structures Research Division of the Langley Aeronautical Laboratory of the NACA, for his help and guidance during this investigation.

EXPERIMENTAL PROCEDURE

The experimental procedure in the work described in this report was generally the same as that in the previous investigation of unnotched and of less severely notched specimens (references 1 and 2).

The material used was supplied from selected stock retained for this purpose at the Langley Aeronautical Laboratory of the NACA. Coupons were cut from 0.090-inch-thick commercial sheets of 24S-T3 and 75S-T6 aluminum alloys and from 0.075-inch-thick commercial sheets of normalized SAE 4130 steel.

Static-strength properties, some of which are repeated from reference 1, are given in table 1.

Figure 1 shows a dimensional drawing of the notched specimen used. The symmetrical edge notch is similar to one of the notch types used in previous work[1] (reference 2). The dimensions of the notch were chosen, on the basis of available information, to give $K_t = 5.0$. The notch was cut with a tool especially designed to produce the contour desired. Machining cuts were successively lighter, so that the depth of each of the last two cuts was about 0.0005 inch. After machining, the notched specimens were electropolished. This removed about 0.0003 inch of material. Each specimen was shadowgraphed after electropolishing; the dimensions shown in figure 1 are those actually measured after this

[1]It was not considered feasible to produce the fillet-type notch with the extremely small radius required to give $K_t = 5.0$ for such a notch.

final step. Table 1 includes static strengths measured for these notched specimens; the effect of the notch on the nominal tensile strength is generally less than 10 percent.

Fatigue tests were run on Krouse direct repeated-stress testing machines at speeds in the range 1100 to 1500 cycles per minute. A description of these machines is given in reference 1. It is estimated that precision of load measurement and maintenance was about ±3 percent in tension-tension tests. In tests involving reversal of load, sheet specimens were restrained from buckling by the use of guide plates. Estimation of precision of loading in such cases was indirect; it is believed that error in load value, in reversed-load testing, did not usually exceed ±5 percent.

FATIGUE TEST RESULTS

Results of axial-load fatigue tests on the severely notched specimens at nominal mean stresses of 0, 10,000, 20,000, and 30,000 psi are given in tables 2, 3, and 4.

These results are plotted in the form of S-N diagrams in figures 2, 3, and 4. All stress values in these diagrams are nominal net-area stresses. While the data are insufficient to afford a statistical evaluation of scatter, it may be noted that the observed points fall closely on the S-N curves drawn.

Figures 5, 6, and 7 show the same results plotted in another manner, as constant-lifetime diagrams of nominal stress amplitude against nominal mean stress. In these derived diagrams, "points" are not directly observed values but are values read from the faired S-N curves in figures 2, 3, and 4.

DISCUSSION

Tables 5, 6, and 7 summarize results of fatigue tests on unnotched specimens and of fatigue tests on specimens with edge notches of various severities. It may be noted that the fatigue strength, for a particular lifetime at a specified mean nominal stress, decreases with increasing notch severity. However, this decrease is not in proportion to the increase in the theoretical stress-concentration factor for the notch.

It is conventional to evaluate the effect of a notch on the fatigue strength of a specimen or structural point in terms of a "fatigue-strength reduction factor." For fully reversed loading, this fatigue-strength reduction factor may be defined as

$$K_f = \frac{\text{Maximum stress for unnotched specimens}}{\text{Maximum stress for notched specimens at same lifetime}}$$

Table 8 shows values of K_f, so defined, for specimens edge-notched with various severities. It may be noted that:

(1) K_f varies with the stress level (being less for high stress levels, corresponding to short lifetimes)

(2) For a specified lifetime, say, 10^7 cycles, K_f increases as the notch severity (indicated by K_t) increases

(3) For a specified lifetime and a specified notch severity, K_f appears to vary for the different materials - being generally least for the 24S-T3 and greatest for the 75S-T6

While the results noted in items (1) and (2) are to be expected, the apparent variation of K_f with materials is not yet fully understood.

As noted in a previous report (reference 2), varied definitions of K_f have been used for fatigue tests at mean stresses other than zero. However, as was the case for less severely notched specimens, none of these variously defined K_f's shows simple correlation with K_t for the full range of materials and stress levels investigated.

It is possible that further investigation, including consideration of possible local deformations and local residual stresses, will afford better understanding of the observed effects of severe notches upon the fatigue strengths of sheet specimens. Until such better understanding is achieved, the designer should use care in extrapolating such test results, recorded in this report, beyond the range covered in the experimental investigation.

CONCLUSIONS

Axial-load fatigue strengths have been obtained for sheet specimens with edge notches having a theoretical stress-concentration factor of 5.0. Tests were made on three materials (24S-T3 and 75S-T6 aluminum alloys and SAE 4130 steel) and at four levels of nominal mean stress (0, 10,000, 20,000, and 30,000 psi).

1. These tests extend information previously obtained on fatigue strengths of unnotched specimens and of specimens with less severe notches.

2. Comparison of results indicates increasing fatigue-strength reduction with increase in notch severity (as indicated by the theoretical stress-concentration factor).

3. The increase in fatigue-strength reduction, however, is not in direct proportion to the increase in theoretical stress-concentration factor of the notch.

Battelle Memorial Institute
Columbus, Ohio, November 30, 1950

REFERENCES

1. Grover, H. J., Bishop, S. M., and Jackson, L. R.: Fatigue Strengths of Aircraft Materials - Axial-Load Fatigue Tests on Unnotched Sheet Specimens of 24S-T3 and 75S-T6 Aluminum Alloys and of SAE 4130 Steel. NACA TN 2324, 1951.

2. Grover, H. J., Bishop, S. M., and Jackson, L. R.: Fatigue Strengths of Aircraft Materials - Axial-Load Fatigue Tests on Notched Sheet Specimens of 24S-T3 and 75S-T6 Aluminum Alloys and of SAE 4130 Steel with Stress-Concentration Factors of 2.0 and 4.0. NACA TN 2389, 1951.

TABLE 1.- STATIC-STRENGTH PROPERTIES OF MATERIALS

Material	Type of specimen	Average tensile properties			Compressive yield strength (psi)
		Elongation in 2 in. (percent)	Yield strength, 0.2-percent offset (psi)	Ultimate strength (psi)	
24S-T3	Unnotched[1]	18.2	54,000	73,000	44,500
	Notched (K_t = 5.0)	----	------	62,400	------
75S-T6	Unnotched[1]	11.4	76,000	82,500	74,000
	Notched (K_t = 5.0)	----	------	77,500	------
SAE 4130	Unnotched[1]	14.3	98,500	117,000	86,000
	Notched (K_t = 5.0)	----	------	121,800	------

[1]From reference 1.

TABLE 2.- AXIAL-LOAD FATIGUE TEST RESULTS FOR 24S-T3 ALUMINUM SHEET

SPECIMENS; EDGE NOTCHED WITH $K_t = 5.0$

Specimen	Nominal maximum stress (psi)	Lifetime, (cycles)	Remarks (1)
Nominal mean stress, 0 psi			
A70-S3	25,000	1,700	
A72-S3	22,500	2,700	
A132-S2	20,000	5,300	
A127-S2	20,000	5,600	
A118-S2	18,000	7,800	
A130-S2	15,000	21,500	
A117-S2	15,000	----------	Counter failed
A116-S2	12,000	68,500	
A120-S2	9,000	205,000	
A122-S2	7,500	585,000	
A119-S2	6,500	763,000	
A133-S2	6,000	6,130,000	
A131-S2	5,750	>10,060,000	Did not fail
Nominal mean stress, 10,000 psi			
A87-S3	32,500	1,000	
A121-S2	30,000	2,200	
A124-S2	28,000	3,200	
A122-S2	25,000	7,000	
A123-S2	23,000	11,000	
A131-S2	20,000	18,500	No guide plates used[2]
A126-S2	17,000	79,000	
A115-S2	15,000	212,000	
A80-S3	14,500	198,000	
A132-S2	14,000	>10,732,000	Did not fail
Nominal mean stress, 20,000 psi			
A71-S2	37,500	1,200	
A118-S2	35,000	3,000	
A117-S2	32,500	6,300	
A116-S2	30,000	12,500	
A129-S2	27,500	27,000	
A134-S2	25,000	96,000	
A79-S3	24,000	175,000	
A133-S2	23,000	>10,140,000	Did not fail
Nominal mean stress, 25,000 psi			
A134-S2	42,000	----------	Incorrectly loaded
A115-S2	42,000	2,000	Failed at notch root
A125-S2	40,000	4,000	Do.
A123-S2	37,500	6,000	Do.
A124-S2	35,000	10,700	Do.
A121-S2	33,000	23,700	Do.
A128-S2	30,500	24,000	Do.
A126-S2	28,000	>10,000,000	Did not fail
Nominal mean stress, 30,000 psi			
A127-S2	47,500	1,300	
A81-S2	45,000	2,200	
A120-S2	42,500	4,500	
A119-S2	42,500	----------	Incorrectly loaded
A128-S2	40,000	9,000	
A125-S2	37,500	22,500	
A130-S2	35,000	73,000	
A78-S2	33,750	268,000	
A75-S2	33,000	>13,298,900	Did not fail
A129-S2	32,500	>13,052,700	Do.

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[1]Unless otherwise noted, specimen failed at notch root.

[2]Ordinarily, guide plates are used when minimum stress is zero, or even slightly higher than zero, to prevent possible buckling at minimum side of stress cycle.

TABLE 3.- AXIAL-LOAD FATIGUE TEST RESULTS FOR 75S-T6 ALUMINUM SHEET SPECIMENS, EDGE NOTCHED WITH $K_t = 5.0$

Specimen	Nominal maximum stress (psi)	Lifetime (cycles)	Remarks (1)
Nominal mean stress, 0 psi			
B63-S3	25,000	2,000	
B51-S3	22,500	3,000	
B53-S3	21,000	3,000	
B50-S3	20,000	4,400	
B69-S3	18,000	6,100	
B52-S3	15,000	15,700	
B55-S3	12,000	36,000	
B61-S3	10,500	83,000	
B66-S3	9,000	273,000	
B54-S3	8,000	500,000	
B56-S3	7,500	277,000	
B59-S3	7,000	1,471,400	
B57-S3	6,500	2,955,900	
B60-S3	6,000	3,500,000	
B64-S3	5,750	7,618,000	
B62-S3	5,500	>10,147,000	Did not fail
Nominal mean stress, 10,000 psi			
B64-S3	32,000	700	
B69-S3	30,000	1,700	
B57-S3	27,500	3,000	
B60-S3	25,000	4,700	
B135-S3	23,000	8,000	
B59-S3	20,000	8,500	No guide plates used[2]
B53-S3	20,000	20,000	
B55-S3	17,500	18,000	
B56-S3	15,000	74,000	
B48-S3	14,000	288,000	
B49-S3	13,500	2,435,000	
B52-S3	13,000	>10,126,000	Did not fail
Nominal mean stress, 20,000 psi			
B65-S3	37,500	900	
B51-S3	35,000	2,000	
B67-S3	32,500	3,400	
B47-S3	30,000	7,500	
B68-S3	27,500	11,000	
B95-S3	25,000	38,500	
B61-S3	24,000	75,000	
B92-S3	23,000	773,000	
B58-S3	22,500	>17,000,000	Did not fail
B91-S3	22,000	>10,000,000	Do.
Nominal mean stress, 30,000 psi			
B53-S2	47,500	900	
B62-S3	45,000	1,500	
B100-S2	42,500	2,700	
B97-S2	40,000	5,000	
B46-S2	37,500	12,000	
B50-S2	35,000	33,500	
B96-S2	33,750	92,500	
B66-S3	33,125	>10,949,000	Did not fail
B94-S2	32,500	>10,516,000	Do.

[1]Unless otherwise noted, specimen failed at notch root.

[2]Ordinarily, guide plates are used when minimum stress is zero, or even slightly higher than zero, to prevent possible buckling at minimum side of stress cycle.

TABLE 4.- AXIAL-LOAD FATIGUE TEST RESULTS OF SAE 4130 STEEL

SHEET SPECIMENS, EDGE NOTCHED WITH $K_t = 5.0$

Specimen	Nominal maximum stress (psi)	Lifetime (cycles)	Remarks (1)
Nominal mean stress, 0 psi			
C195-S2	46,500	6,800	
C233-S2	45,000	3,000	
C231-S2	45,000	5,400	
C228-S2	40,000	15,700	
C225-S2	35,000	24,500	
C232-S2	30,000	48,000	
C222-S2	25,000	140,000	
C218-S2	17,500	340,000	
C230-S2	15,000	926,000	
C226-S2	14,000	950,000	
C221-S2	12,500	1,071,400	
C235-S2	10,000	>10,415,000	Did not fail
Nominal mean stress, 10,000 psi			
C177-S2	55,000	3,000	
C166-S2	50,000	4,000	
C228-S2	45,000	8,000	
C220-S2	40,000	22,000	
C217-S2	35,000	38,000	
C233-S2	30,000	82,000	
C192-S2	28,000	134,000	
C182-S2	25,000	230,000	
C55-S2	23,000	472,000	
C186-S2	22,500	495,000	
C196-S2	20,000	>11,510,000	Did not fail
Nominal mean stress, 20,000 psi			
C198-S2	65,000	2,300	
C231-S2	60,000	3,800	
C224-S2	55,000	6,000	
C230-S2	50,000	13,700	
C229-S2	45,000	30,000	
C226-S2	40,000	36,000	
C172-S2	35,000	88,000	
C181-S2	32,500	215,000	
C188-S2	30,000	>18,267,500	Did not fail
Nominal mean stress, 30,000 psi			
C194-S2	75,000	1,800	
C216-S2	70,000	3,000	
C232-S2	65,000	5,000	
C234-S2	60,000	6,000	
C218-S2	55,000	11,500	
C223-S2	50,000	25,500	
C235-S2	45,000	53,500	
C227-S2	42,500	117,000	
C219-S2	40,000	1,798,000	
C180-S2	37,500	>13,145,000	Did not fail

[1]Unless otherwise noted, specimen failed at notch root.

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TABLE 5.- SUMMARY OF FATIGUE TEST RESULTS FOR 24S-T3 ALUMINUM

SHEET SPECIMENS WITH EDGE NOTCHES

Nominal mean stress (psi)	Notch severity, K_t	Nominal maximum stress (psi) at lifetime (cycles) of -						
		5×10^3	10^4	5×10^4	10^5	5×10^5	10^6	10^7
0×10^3	1	54.0×10^3	50.0×10^3	42.0×10^3	34.0×10^3	28.0×10^3	24.0×10^3	22.0×10^3
	2	33.0	29.5	21.0	16.5	15.0	14.0	12.0
	4	21.0	18.0	12.5	10.0	8.0	7.5	7.0
	5	20.0	17.5	12.3	11.0	8.0	7.0	6.5
10	1	----------	60.0	47.0	41.0	32.0	30.5	29.0
	2	42.0	38.0	29.0	25.5	21.5	21.0	21.0
	4	28.5	25.0	20.0	16.0	15.5	15.0	15.0
	5	26.5	23.5	18.0	16.5	15.0	14.8	14.5
20	1	----------	65.0	53.0	46.0	39.5	39.0	38.0
	2	52.0	48.0	38.0	34.0	30.0	30.0	30.0
	4	35.0	32.0	27.0	25.0	25.0	24.0	24.0
	5	33.0	31.0	26.0	25.0	24.2	24.0	23.5
30	1	----------	70.0	59.0	54.0	48.0	47.0	46.0
	2	59.0	56.0	47.0	43.0	39.5	39.0	39.0
	4	45.0	41.0	36.0	35.0	34.0	34.0	34.0
	5	42.3	40.0	36.0	34.7	33.8	33.3	33.0

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TABLE 6.- SUMMARY OF FATIGUE TEST RESULTS FOR 75S-T6 ALUMINUM

SHEET SPECIMENS WITH EDGE NOTCHES

Nominal mean stress (psi)	Notch severity, K_t	Nominal maximum stress (psi) at lifetime (cycles) of -						
		5×10^3	10^4	5×10^4	10^5	5×10^5	10^6	10^7
0×10^3	1	----------	53.0×10^3	41.0×10^3	35.0×10^3	32.5×10^3	32.0×10^3	30.0×10^3
	2	35.0×10^3	31.0	24.0	20.0	17.5	16.5	15.5
	4	20.0	17.0	13.0	11.0	8.5	8.0	7.5
	5	20.0	16.5	11.5	10.0	8.0	7.3	6.0
10	1	----------	62.0	47.0	40.0	39.0	36.0	35.0
	2	42.0	38.0	29.5	26.5	24.5	23.5	23.0
	4	27.0	23.0	18.0	16.0	15.0	14.0	14.0
	5	25.0	21.0	15.5	15.0	14.0	14.0	13.5
20	1	----------	70.0	52.0	45.0	43.0	42.0	41.0
	2	50.0	46.0	33.0	32.0	30.0	29.5	29.5
	4	33.0	31.0	25.0	24.0	23.0	23.0	23.0
	5	31.0	28.5	24.5	23.7	23.0	22.7	22.5
30	1	----------	75.0	58.5	54.0	50.0	49.0	49.0
	2	59.5	53.0	42.0	39.5	38.5	38.5	38.5
	4	42.0	39.0	34.0	34.0	33.0	33.0	33.0
	5	40.0	38.5	34.7	34.0	33.5	33.5	33.3

TABLE 7.- SUMMARY OF FATIGUE TEST RESULTS FOR SAE 4130 STEEL

SHEET SPECIMENS WITH EDGE NOTCHES

Nominal mean stress (psi)	Notch severity, K_t	Nominal maximum stress[1] (psi) at lifetime (cycles) of -						
		5×10^3	10^4	5×10^4	10^5	5×10^5	10^6	10^7
0×10^3	1	----	75.0×10^3	65.0×10^3	63.0×10^3	55.0×10^3	52.0×10^3	47.0×10^3
	2	----	(55.0)	44.5	40.0	33.0	30.0	27.0
	4	----	45.0	32.0	27.0	19.0	16.0	14.0
	5	----	43.0	30.0	25.0	16.0	13.0	10.0
10	1	----	87.0	79.0	73.0	68.0	60.0	60.0
	2	----	(64.0)	54.0	50.0	41.5	39.0	37.0
	4	----	52.0	38.0	34.0	25.0	23.0	23.0
	5	----	43.5	33.0	29.5	23.0	21.0	20.0
20	1	----	95.0	87.0	81.0	75.0	68.0	68.0
	2	----	(76.0)	65.0	60.0	50.0	47.0	45.0
	4	----	58.0	45.0	41.0	34.0	34.0	33.0
	5	----	51.0	39.5	35.0	31.0	30.5	30.0
30	1	----	103.0	93.0	89.0	82.0	76.0	76.0
	2	----	(85.0)	72.0	69.0	58.0	57.0	57.0
	4	----	64.0	52.0	49.0	44.0	44.0	43.0
	5	----	55.5	45.5	43.0	40.5	40.0	39.0

[1]Parentheses indicate value obtained by extrapolation.

TABLE 8.- FATIGUE-STRENGTH REDUCTION FACTORS FOR FULLY REVERSED

AXIAL-LOADING TESTS ON EDGE-NOTCHED SHEET SPECIMENS

Material	Notch severity, K_t	Fatigue-strength reduction factors,[1] K_f, at zero mean stress, at lifetime (cycles) of -			
		10^4	10^5	10^6	10^7
24S-T3 aluminum alloy	2	1.7	2.1	1.9	1.8
	4	2.8	3.4	3.5	3.2
	5	2.9	3.1	3.5	3.4
75S-T6 aluminum alloy	2	1.7	1.8	1.9	1.9
	4	3.2	3.2	4.0	4.0
	5	3.3	3.5	4.4	5.0
SAE 4130 steel	2	(1.4)	1.6	1.7	1.7
	4	1.7	2.3	3.3	3.4
	5	1.7	2.5	4.0	4.7

[1]Parentheses indicate value obtained by extrapolation.

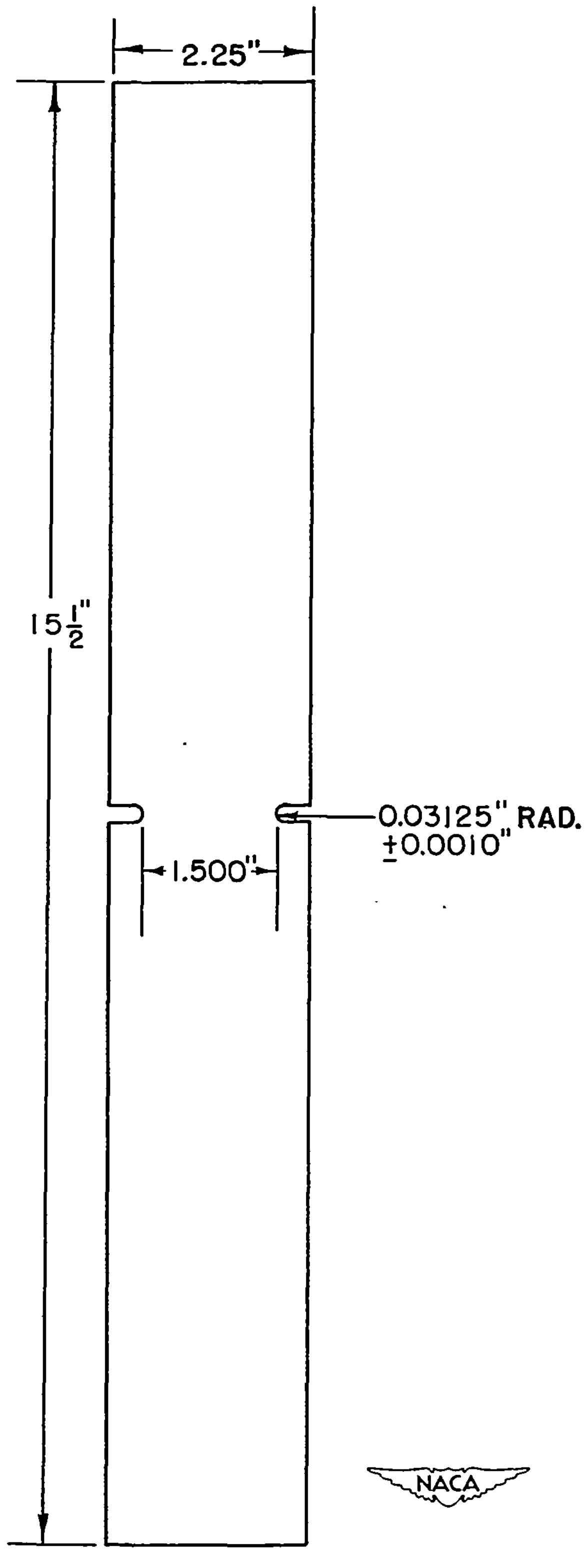

Figure 1.- Notched fatigue test specimen with $K_t = 5$.

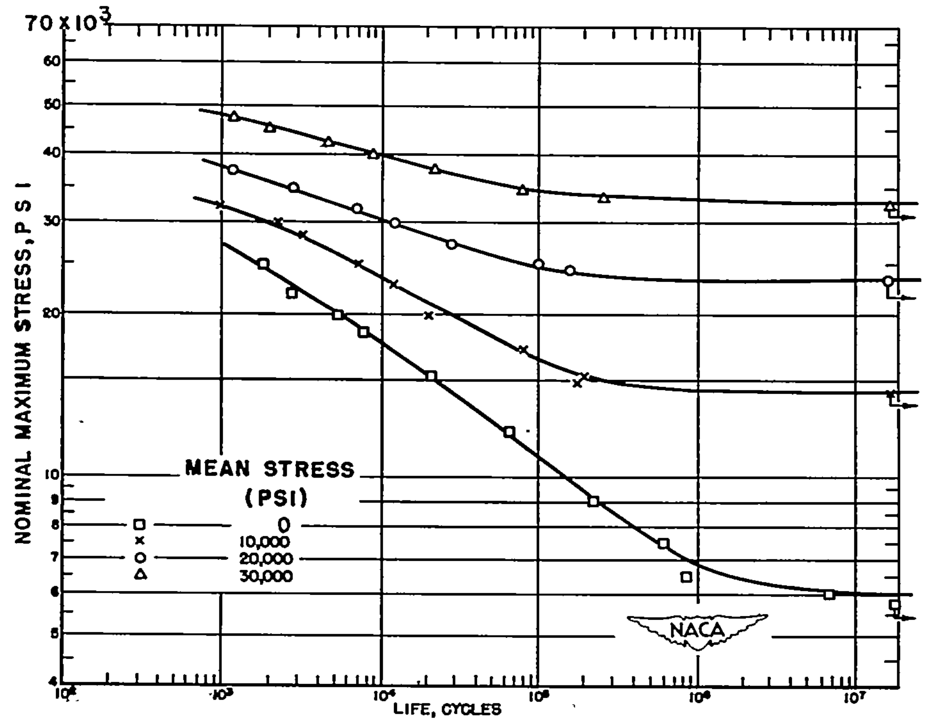

Figure 2.- Results of axial-load fatigue tests on notched 24S-T3 aluminum sheet specimens. Edge-cut notch; $K_t = 5$.

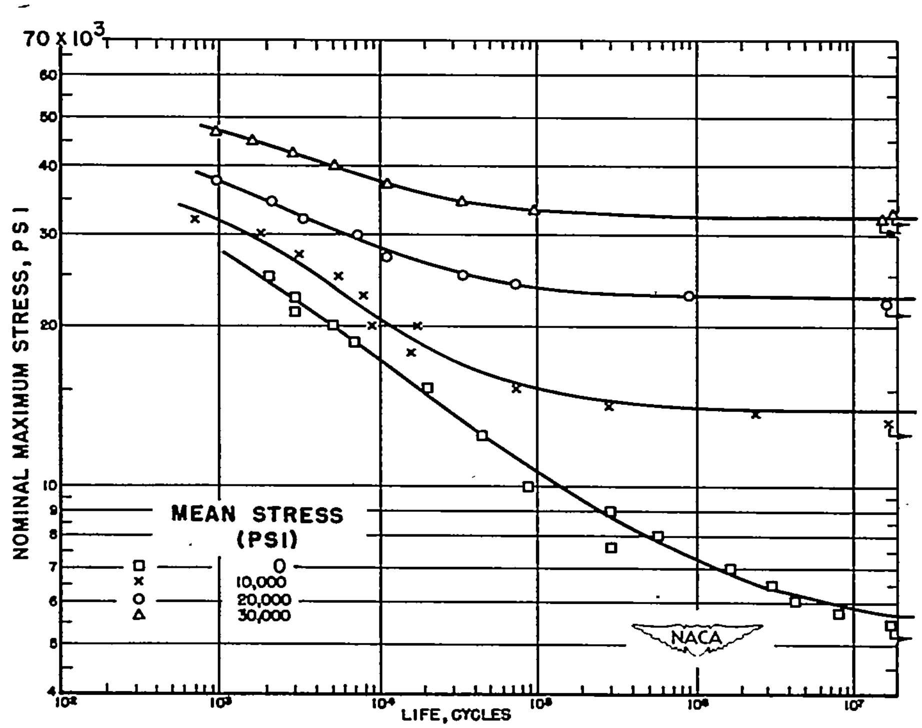

Figure 3.- Results of axial-load fatigue tests on notched 75S-T6 aluminum sheet specimens. Edge-cut notch; $K_t = 5$.

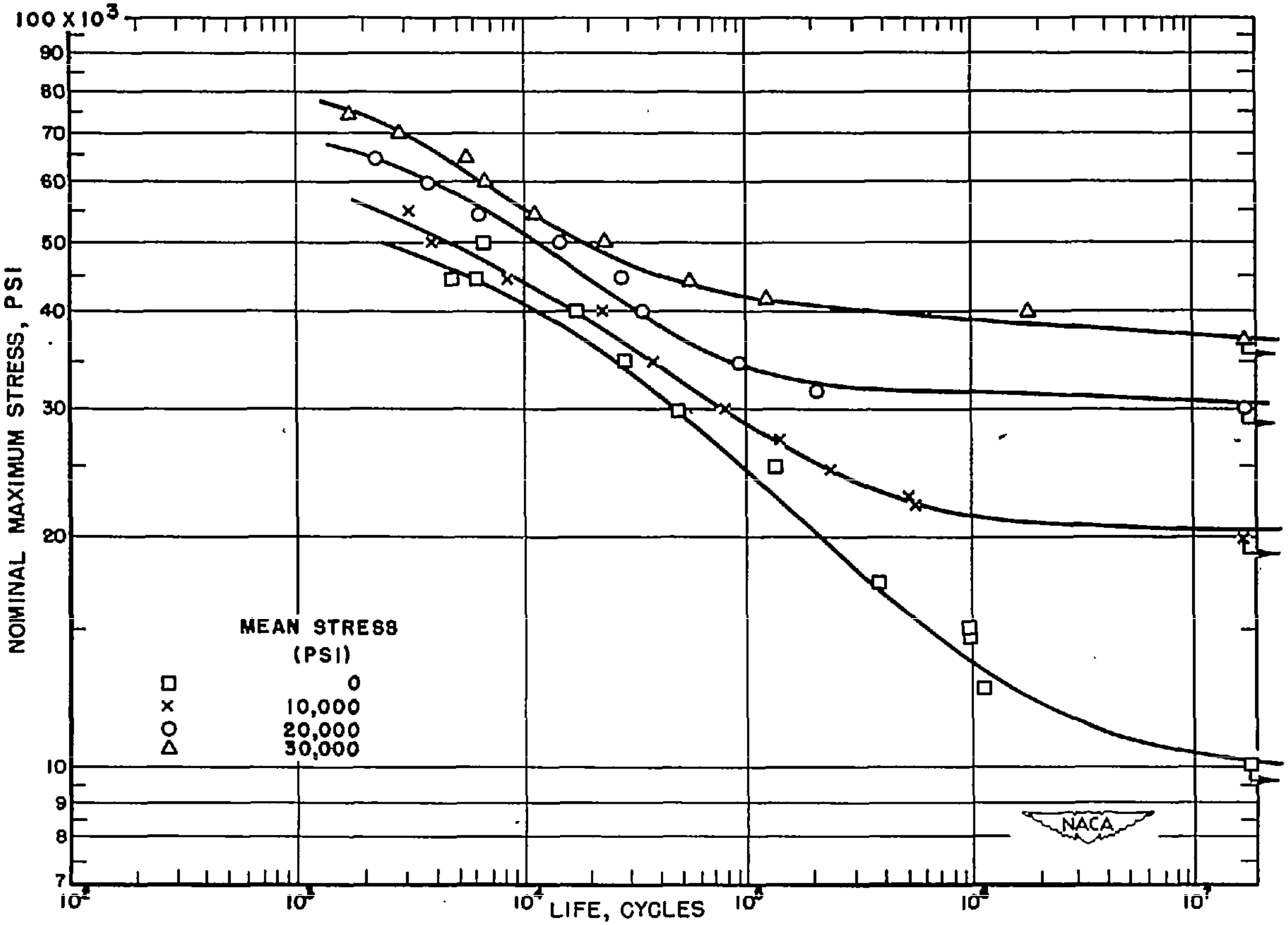

Figure 4.- Results of axial-load fatigue tests on notched SAE 4130 steel sheet specimens. Edge-cut notch; $K_t = 5$.

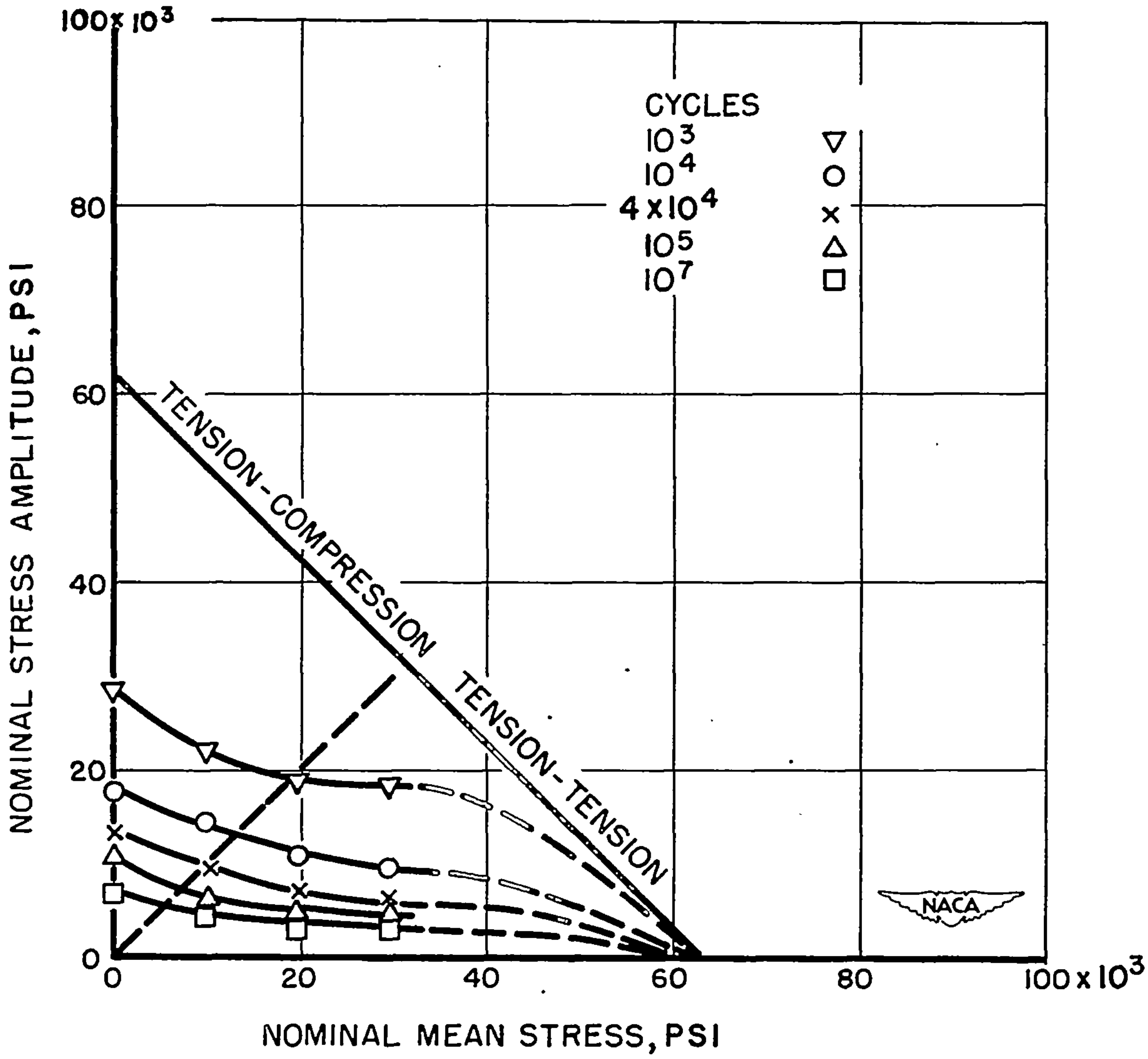

Figure 5.- Constant-lifetime curves for 24S-T3 aluminum sheet notched with an edge-cut notch. $K_t = 5$.

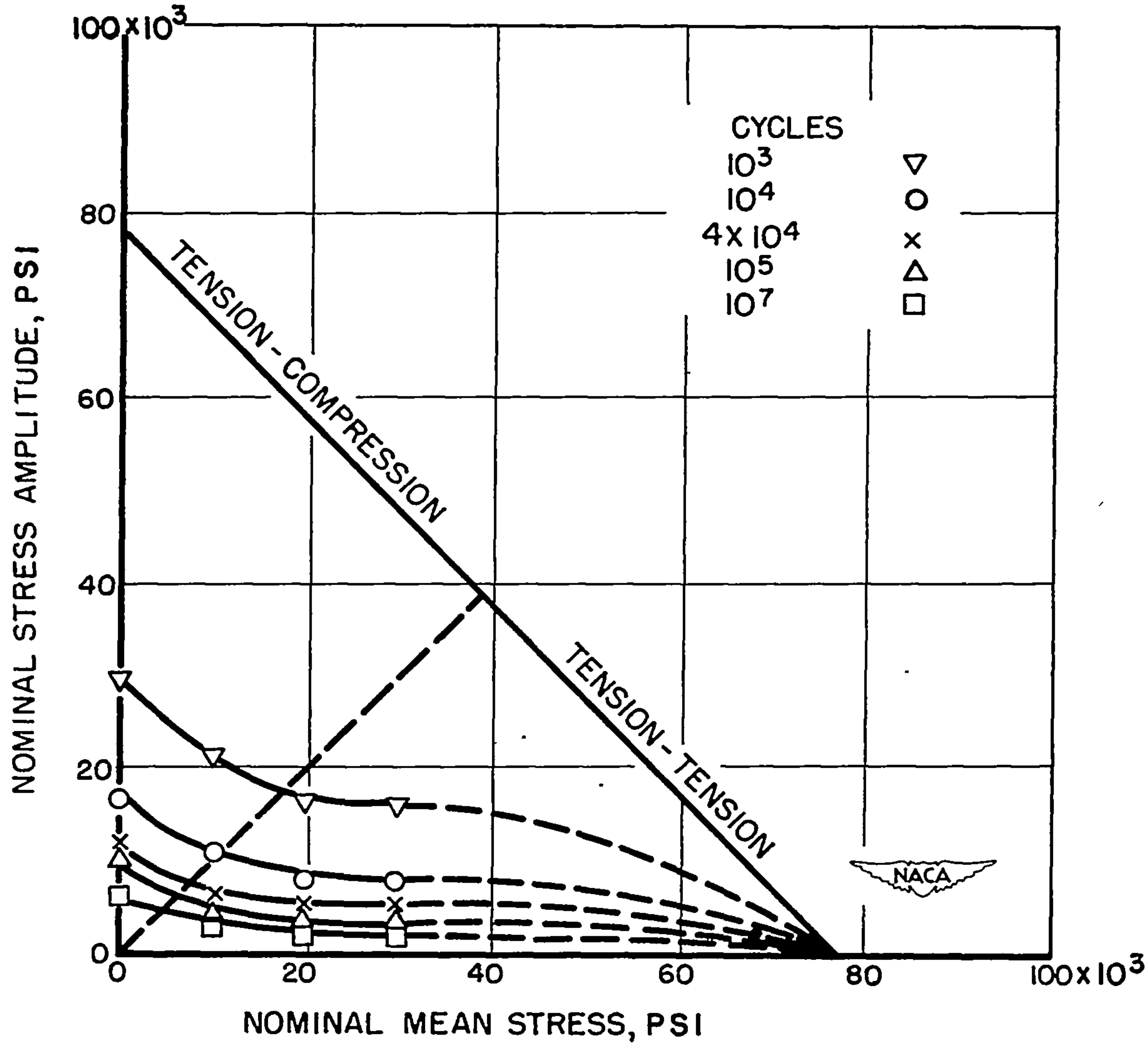

Figure 6.- Constant-lifetime curves for 75S-T6 aluminum sheet notched with an edge-cut notch. $K_t = 5$.

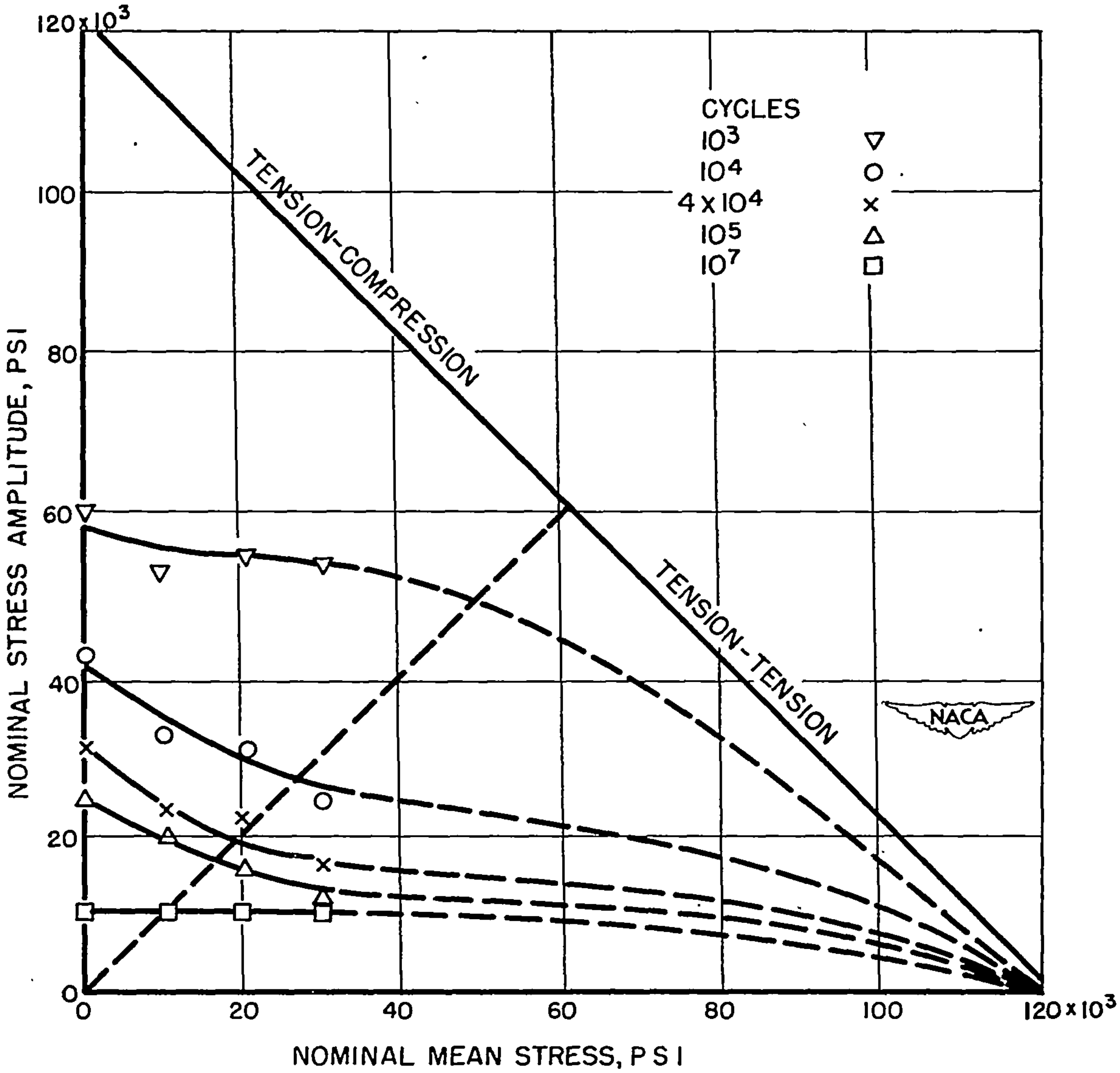

Figure 7.- Constant-lifetime curves for SAE 4130 steel sheet notched with an edge-cut notch. $K_t = 5$.